



# Interchange motions and intermittent transport in TCV SOL plasmas

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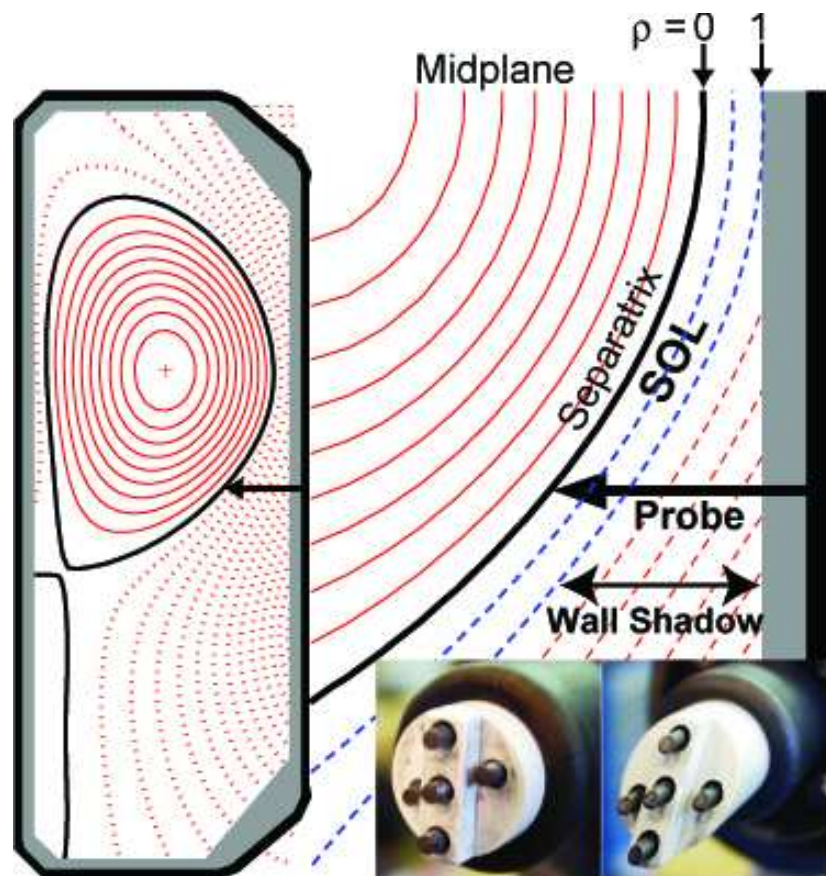
# TCV Experiment

Ohmically heated, 340 kA, density ramp pulses

Single lower null magnetic configuration

Two probe reciprocations for each experiment

Line averaged densities of  $4.5$  and  $11 \times 10^{19} \text{ m}^{-3}$



# ESEL Turbulence Simulations

Two-dimensional domain at the outer midplane

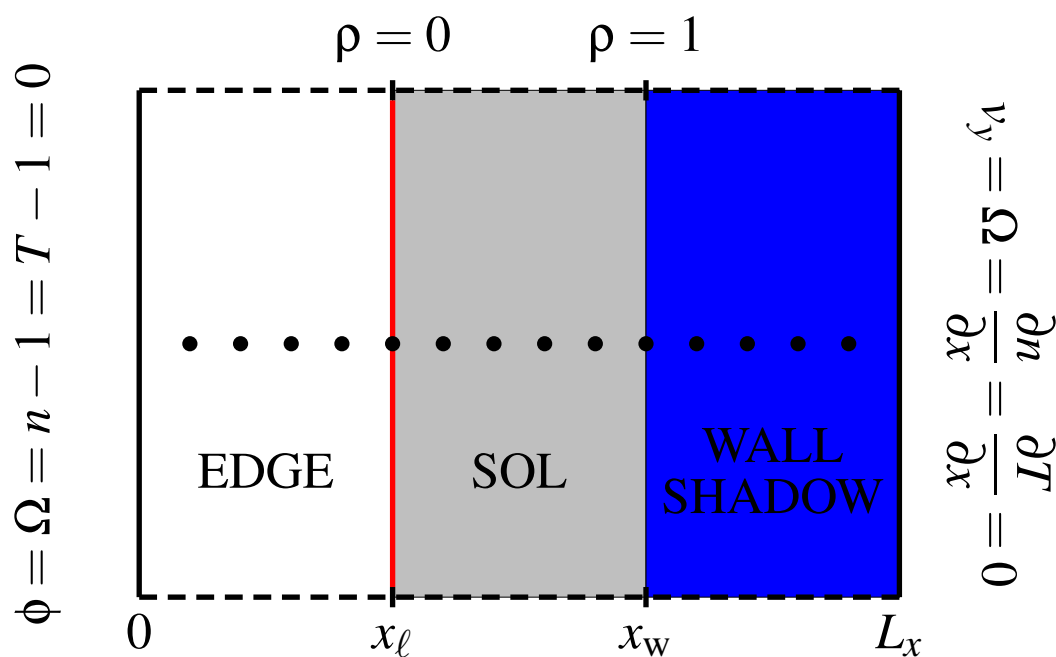
Vorticity, electron density and temperature evolution

Collective motions driven by the non-uniform  $\mathbf{B}$  field

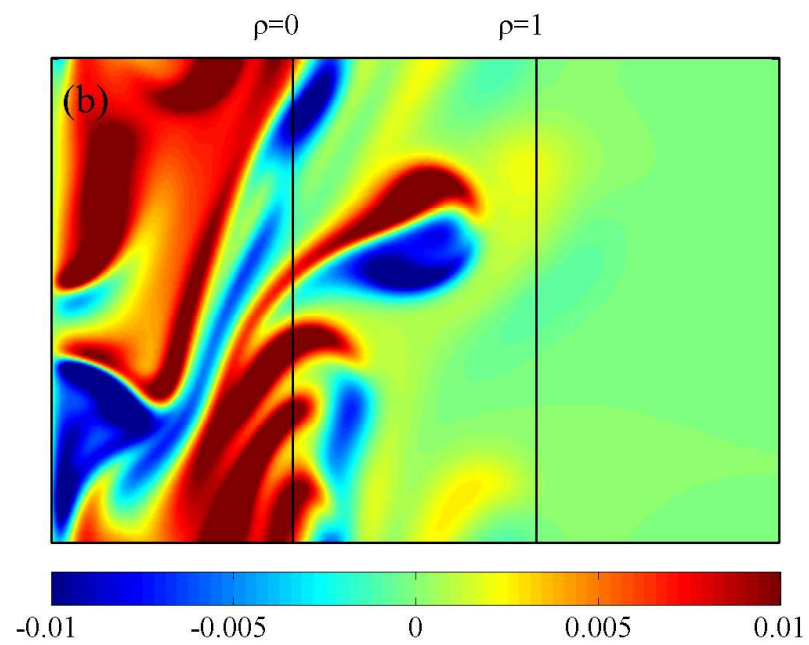
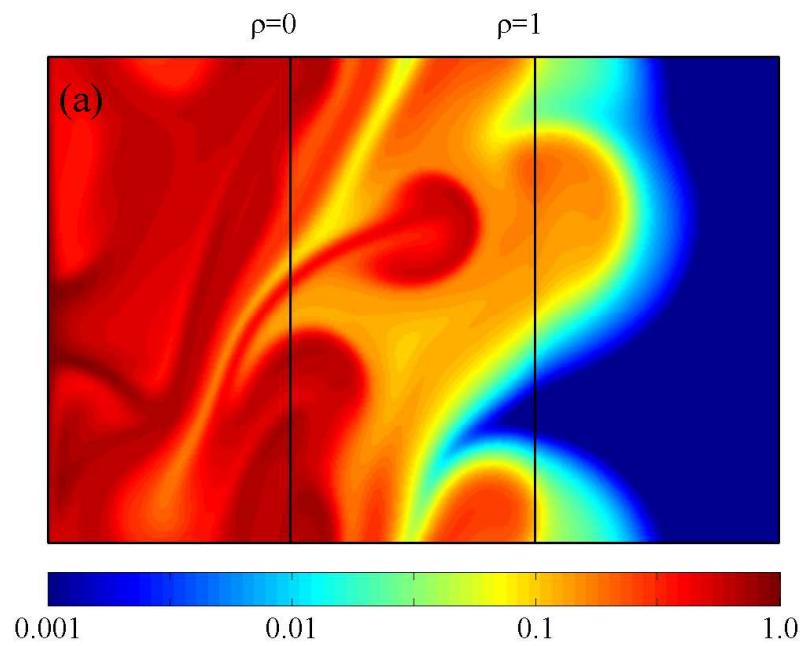
Linear SOL damping terms due to parallel transport

Model parameters set by the high density TCV case

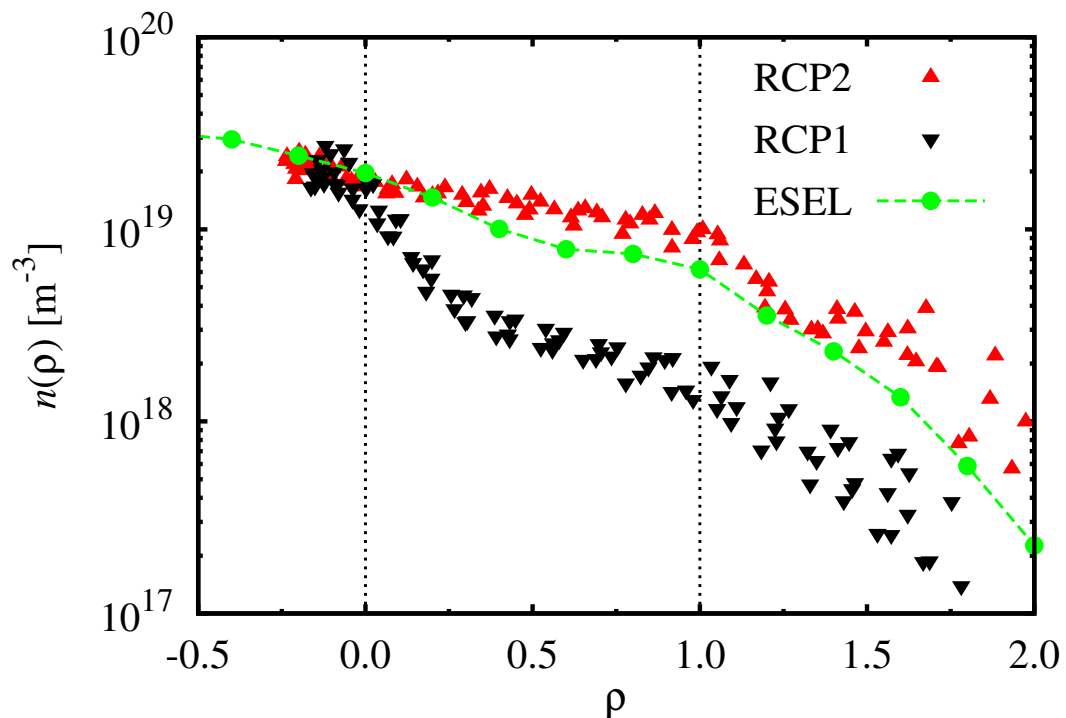
Long time series recorded by an array of probes



# Density and Vorticity Structures



# Time-Averaged Density Profiles



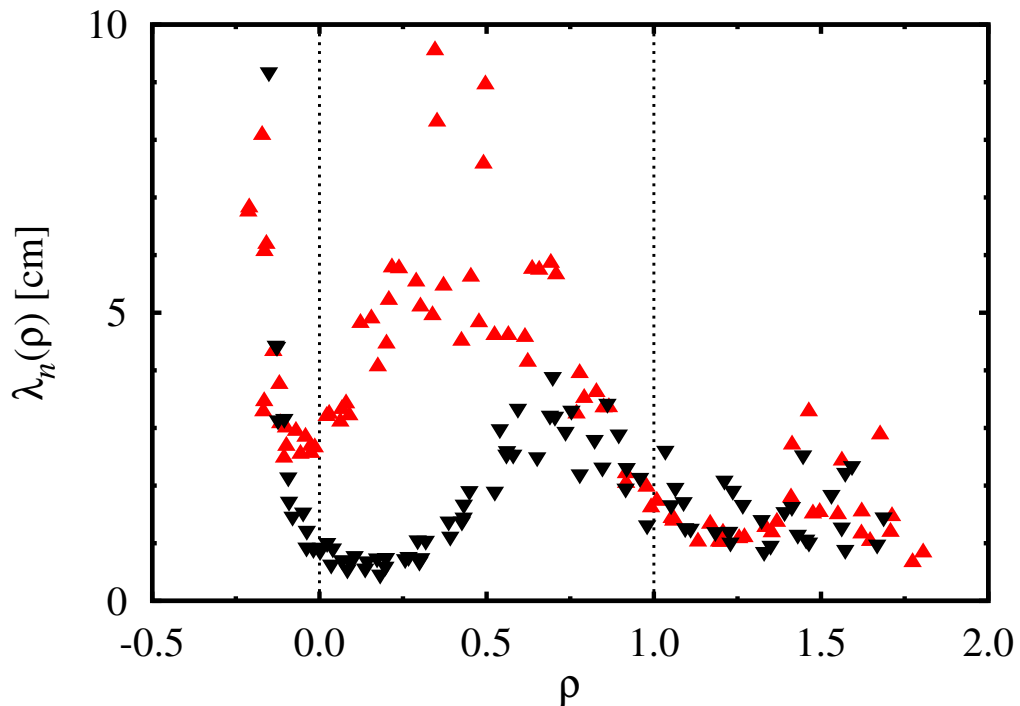
Low density case (RCP1)

- steep profile in the vicinity of the separatrix
- broad profile in the outer half of the SOL

High density case (RCP2)

- broad profile throughout the main SOL region
- well matched by ESEL turbulence simulation

# Exponential Density Scale Lengths



Exponential density profile scale length defined by

$$\lambda_n = -\frac{n}{\partial n / \partial r} = -\frac{1}{\partial \ln n / \partial r},$$

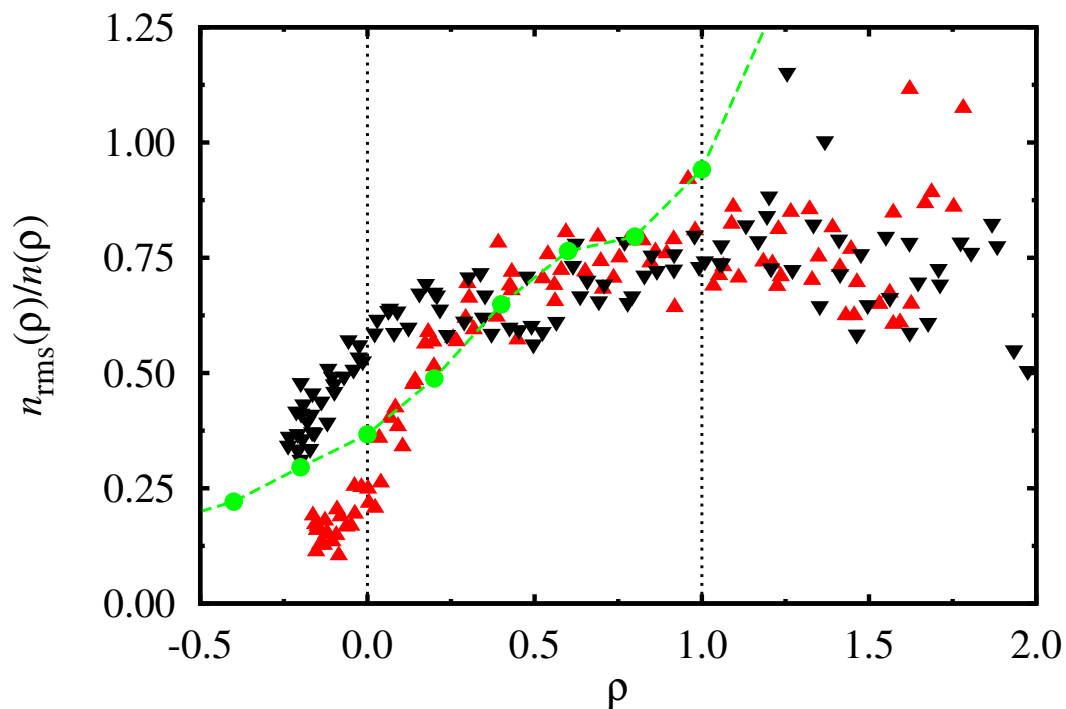
Low density case (RCP1)

- $\lambda_n \approx 0.5$  cm in near SOL and 2.3 cm in far SOL

High density case (RCP2)

- $\lambda_n \approx 4.5$  cm for mid SOL and 3.8 cm for all SOL

## Relative Density Fluctuation Level



Relative fluctuation level of order unity in both cases

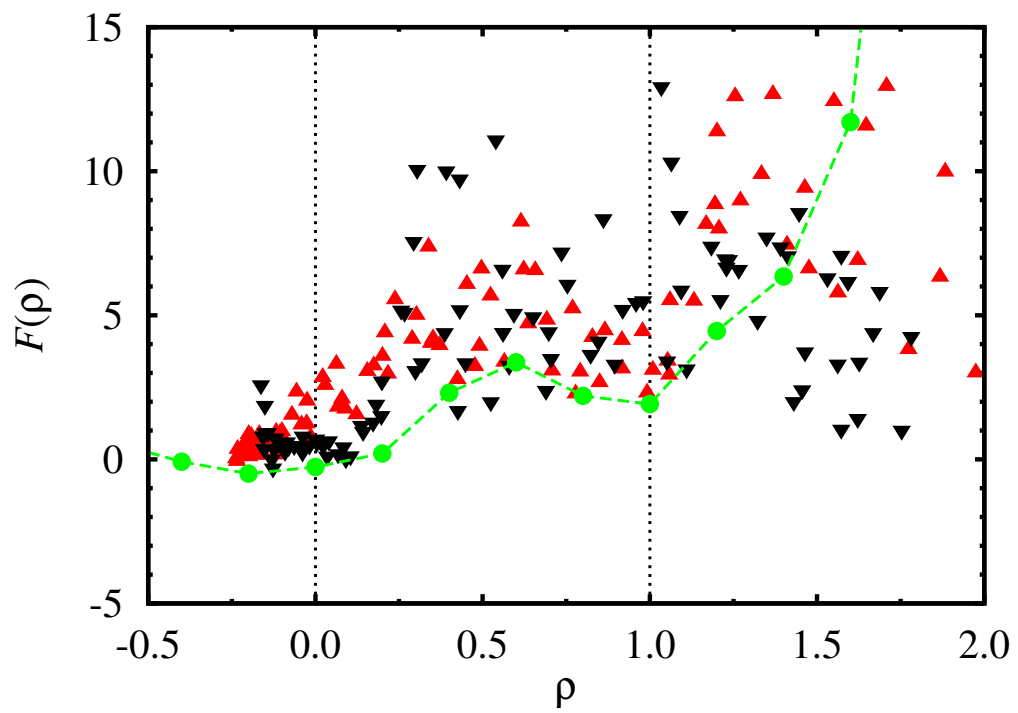
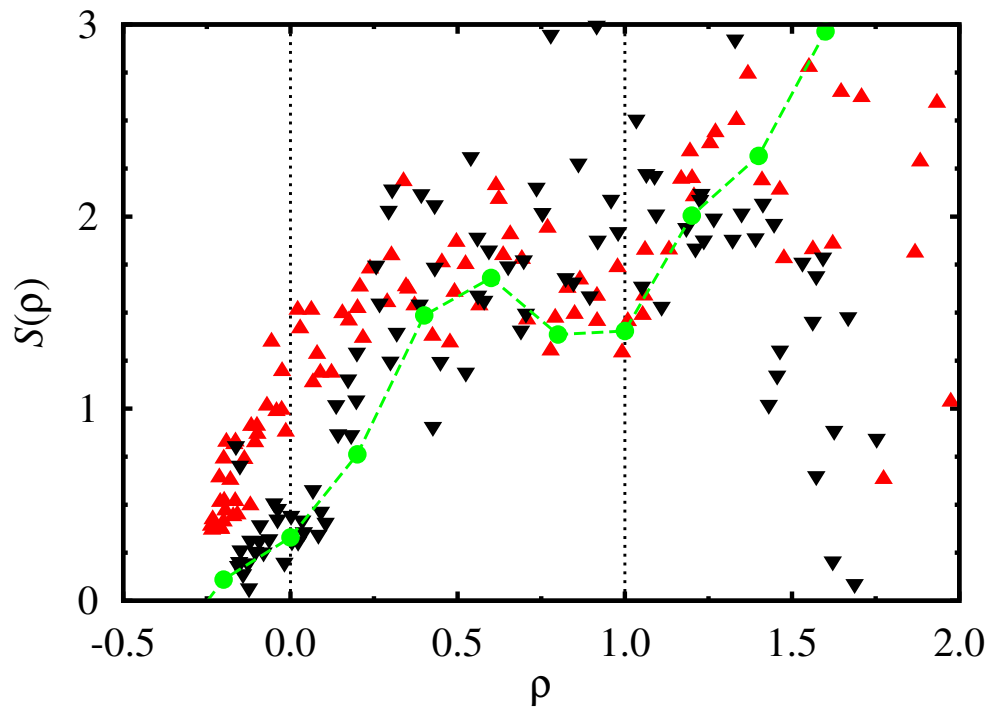
The same radial variation in broad profile regions

Well matched by ESEL turbulence simulation

The same goes for skewness and flatness moments

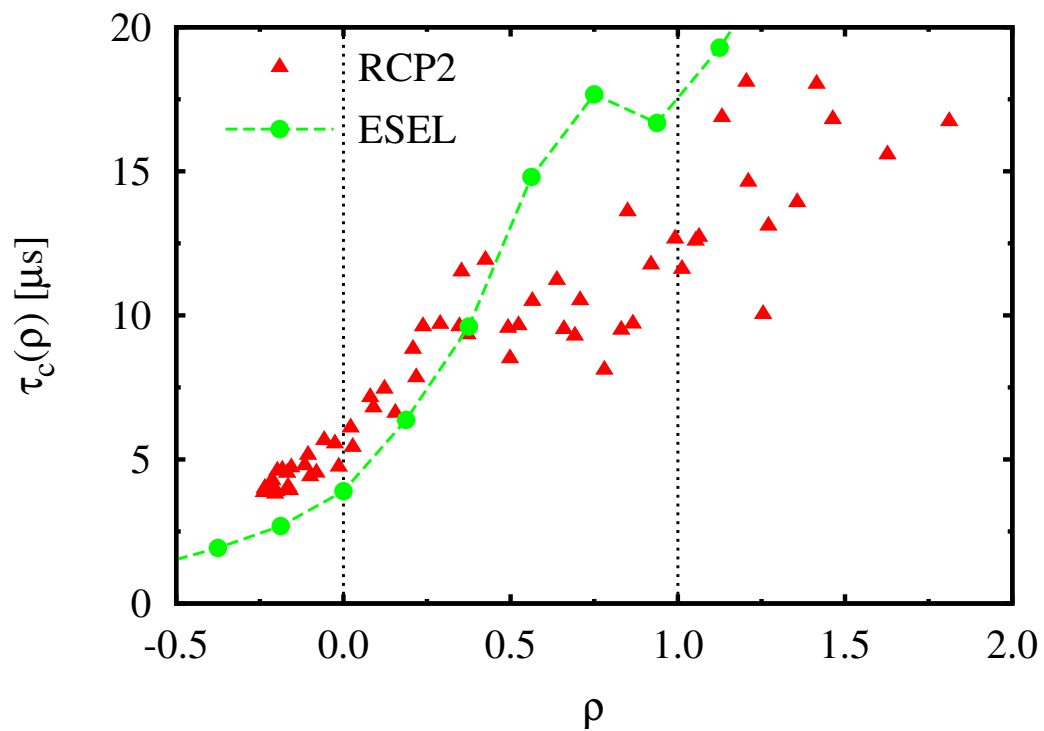
Even more goodies given in PPCF **48** L1 (2006)

## Density Skewness and Flatness





## Density Correlation Times



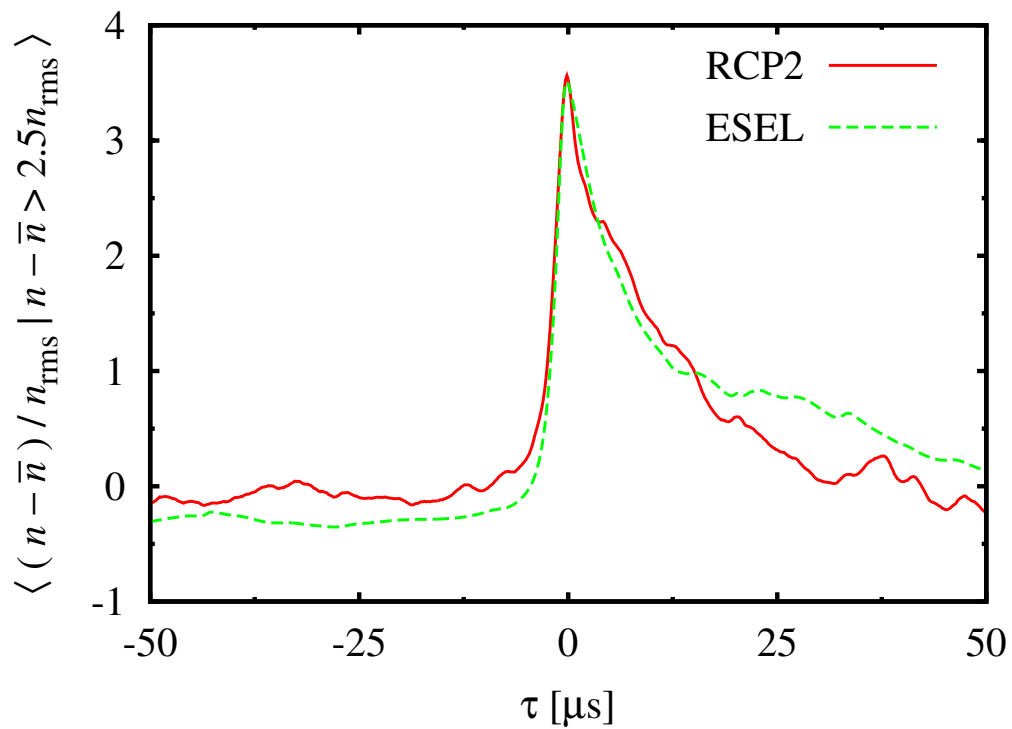
Correlation times increase radially outwards

Also poloidal flow decreases radially outwards

Consistent with blob dispersion and deceleration

Well matched by ESEL turbulence simulation

## Density Conditional Average



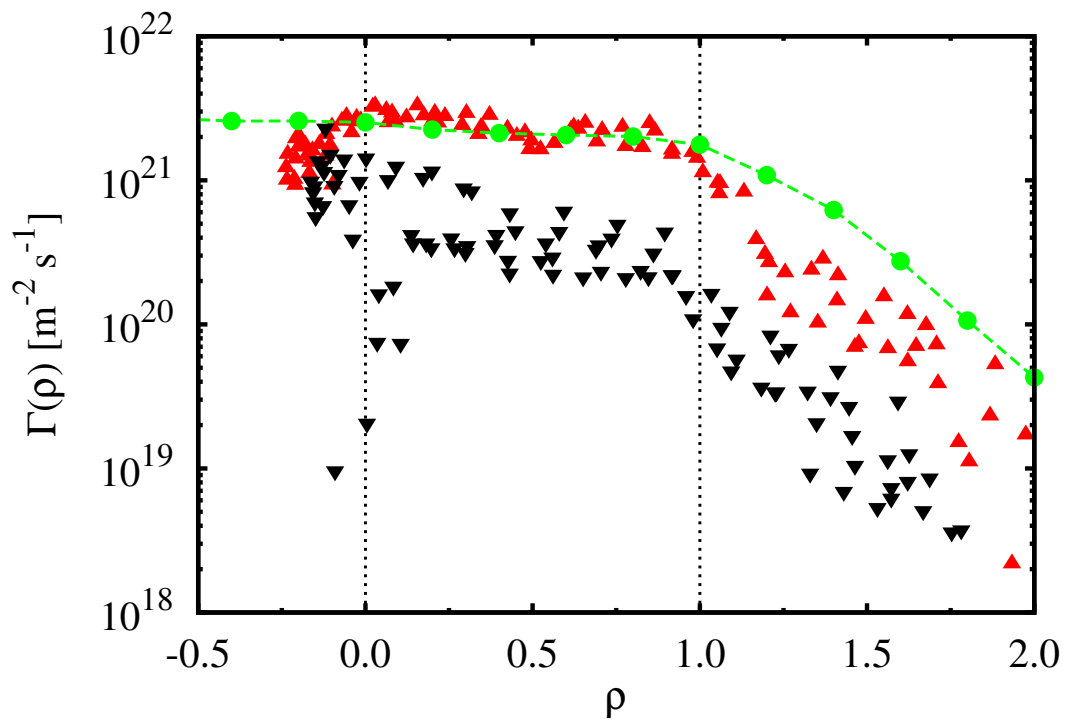
Time series dominated by large-amplitude bursts

Asymmetric shape with steep front and trailing wake

Due to radial motion of blobs in the simulations

Well matched by ESEL turbulence simulation

## Turbulent Particle Flux Density



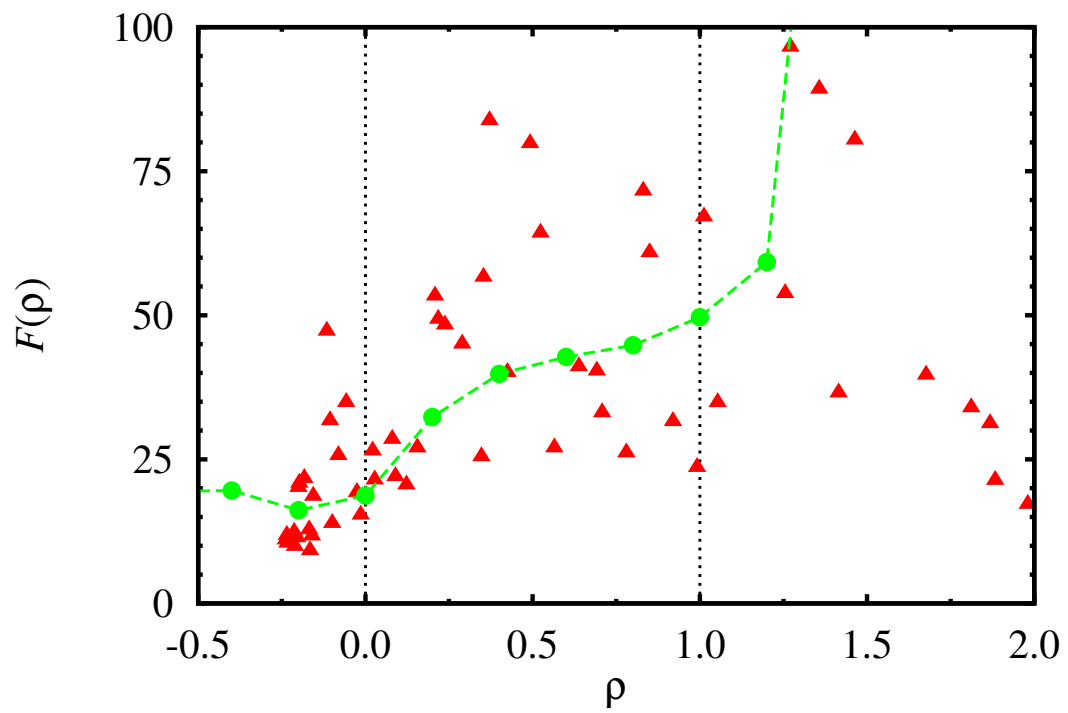
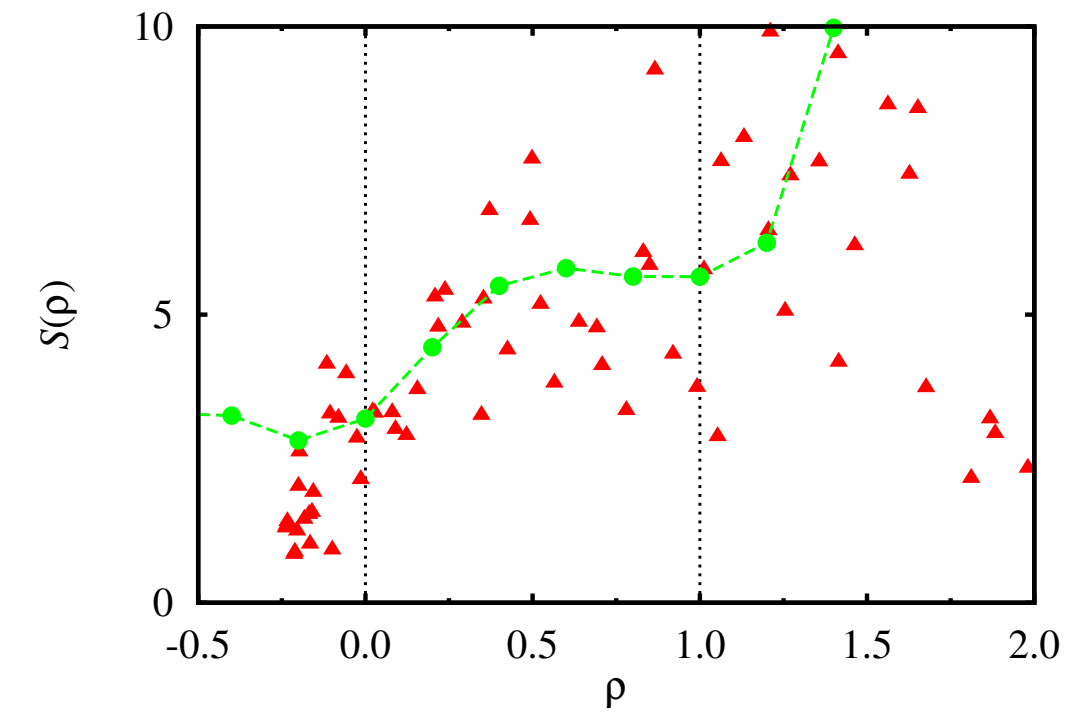
Factor 5 difference at LCFS between RCP1 & 2

Flux almost radially constant in high density case

Well matched by ESEL turbulence simulation

The same goes for the flux fluctuation statistics

## Flux Skewness and Flatness



## Turbulent Flux Parameterization

Formally define an effective diffusion coefficient

$$\Gamma = -D_{\text{eff}} \frac{\partial n}{\partial r} = \frac{n D_{\text{eff}}}{\lambda_n}.$$

and an effective convective velocity

$$\Gamma = n V_{\text{eff}}.$$

Using the separatrix values for the high density case,

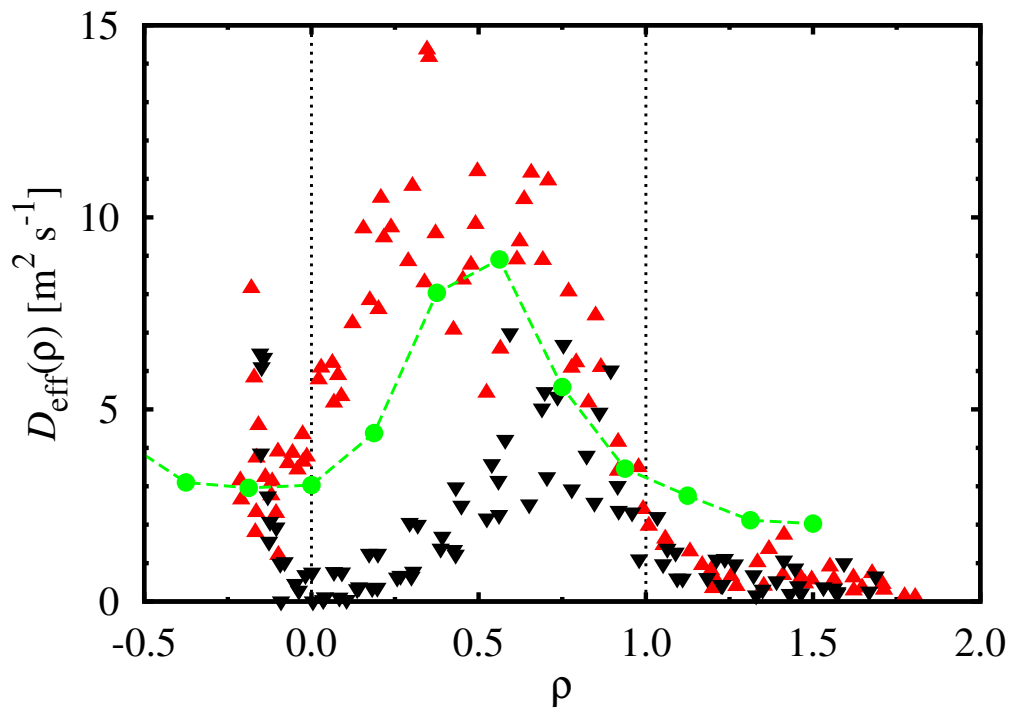
$$n \approx 2 \times 10^{19} \text{ m}^{-3}, \quad \Gamma \approx 3 \times 10^{21} \text{ m}^{-2} \text{ s}^{-1} \quad \lambda_n \approx 4 \text{ cm},$$

yields the transport coefficients

$$D_{\text{eff}} = 6 \text{ m}^2 \text{ s}^{-1}, \quad V_{\text{eff}} = 150 \text{ m s}^{-1}.$$

In comparison,  $D_{\text{Bohm}} = 1 \text{ m}^2 \text{ s}^{-1}$ .

## Effective Diffusion



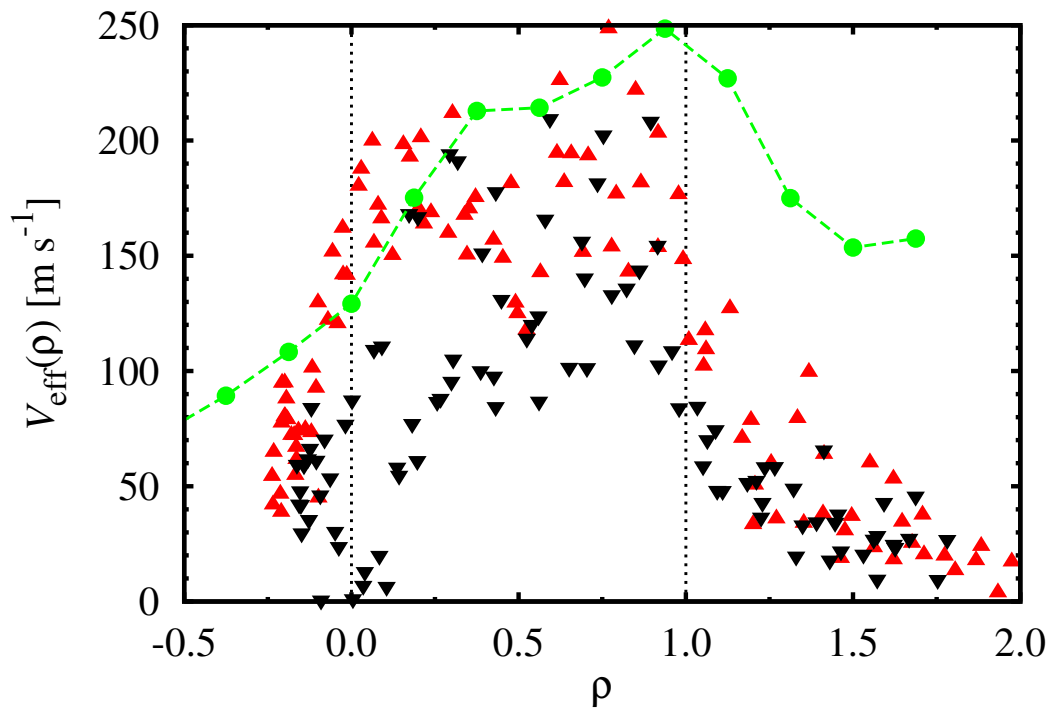
$D_{\text{eff}}$  defined by  $\lambda_n \Gamma / n$

Strong radial variation of  $D_{\text{eff}}$  for both cases

RCP1 & 2 differs both in shape and magnitude

RCP2 well matched by ESEL turbulence simulation

## Effective Convection



$V_{\text{eff}}$  defined by  $\Gamma/n$

Strong radial variation for low density case

$V_{\text{eff}}$  roughly constant for the high density case

Same value of  $V_{\text{eff}}$  in the region with broad profiles

RCP2 well matched by ESEL turbulence simulation

## Effective Diffusion and Convection

Assume a simple linear combination of diffusion and convection,

$$\Gamma = -\hat{D}_{\text{eff}} \frac{\partial n}{\partial r} + n \hat{V}_{\text{eff}}.$$

Ratio of the particle flux and number density becomes

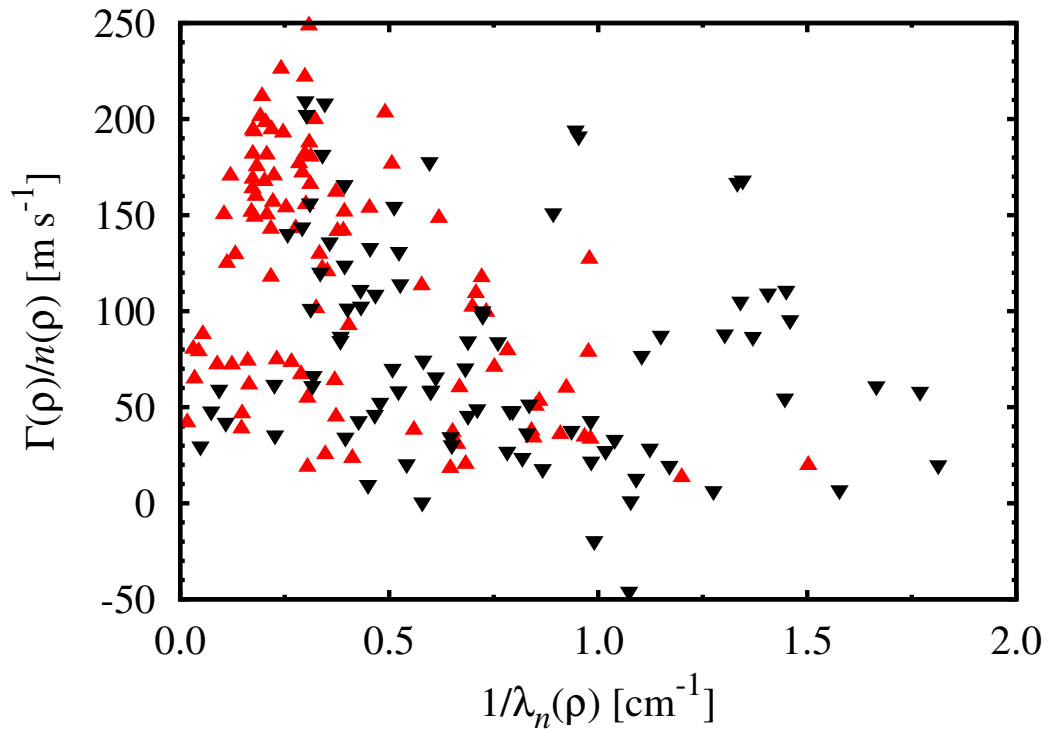
$$\frac{\Gamma}{n} = \hat{V}_{\text{eff}} - \frac{\hat{D}_{\text{eff}}}{n} \frac{\partial n}{\partial r} = \hat{V}_{\text{eff}} + \frac{\hat{D}_{\text{eff}}}{\lambda_n}.$$

For constant coefficients a plot of  $\Gamma/n$  vs  $1/\lambda_n$  gives

- $\hat{D}_{\text{eff}}$  from the slope of the curve
- $\hat{V}_{\text{eff}}$  from the intersection with the ordinate



## Effective Diffusion and Convection II



Experimental data reveal no linear curve

There even seems to be no functional dependence

No reliable flux parameterization exists for these data

Contradicts the traditional flux–gradient paradigm

Not surprising given  $n_{\text{rms}} \sim n$  and  $\lambda_{\text{correlation}} \sim \lambda_n$

No theoretical foundation for effective diffusion

## Conclusions

Time-averaged plasma profiles in the TCV SOL show a behavior with increasing line averaged density like many other experiments: The profile becomes broader in both scale length and radial extent.

Despite this, the fluctuation statistics in the region of broad plasma profiles remain the same, again manifesting the universal statistical properties seen in TCV probe time series.

Two-dimensional interchange turbulence simulations are in quantitative agreement with experimental measurements and reveal intermittent plasma transport due to radial motion of plasma filaments.

For the TCV SOL data analyzed here, there does not seem to be any reliable parameterization of the turbulent flux in terms of effective diffusion and convection coefficients.

# References

## TCV Experiments

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Plasma Phys. Control. Fusion **47** L1 (2005)

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## ESEL Simulations

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## Isolated Blob Theory

Phys. Plasmas **10** 671 (2003)

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